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A Cursory Examination of a Parachute Bag Knife, P/N 71172

by Marc Pepi and Victor Champagne

ARL-TR-3892

September 2006

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
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1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE		3. DATES COVERED (From - To)	
September 2006	Final		March 2006	
4. TITLE AND SUBTITLE			5a. CONTRACT NUMBER	
A Cursory Examination of a Parachute Bag Knife, P/N 71172			5b. GRANT NUMBER	
			5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)			5d. PROJECT NUMBER	
Marc Pepi and Victor Champagne			680L31	
			5e. TASK NUMBER	
			5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)			8. PERFORMING ORGANIZATION REPORT NUMBER	
U.S. Army Research Laboratory ATTN: AMSRD-ARL-WM-MC Aberdeen Proving Ground, MD 21005-5069			ARL-TR-3892	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S)	
Natick Research, Development and Engineering Center Natick Soldier Center Natick, MA 01760			NRDEC	
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT				
Approved for public release; distribution is unlimited.				
13. SUPPLEMENTARY NOTES				
14. ABSTRACT				
A parachute bag knife was received for a “quick-look” analysis to determine the reason for edge deformation after normal use. The U.S. Army Research Laboratory performed hardness testing, chemical analysis, and metallography. Hardness testing in conjunction with metallography showed a layer of decarburization around the periphery of the knife (not on the blade edge, however). Chemical analysis verified alloy AISI 4130 was used. Metallography also revealed a less than optimal microstructure for this alloy. It was recommended that future parts be quenched and tempered to produce a tougher knife edge.				
15. SUBJECT TERMS				
failure analysis, parachute bag knife, metallography				
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES
a. REPORT UNCLASSIFIED	b. ABSTRACT UNCLASSIFIED	c. THIS PAGE UNCLASSIFIED	UL	24
			19b. TELEPHONE NUMBER (Include area code) 410-306-0848	

Standard Form 298 (Rev. 8/98)

Prescribed by ANSI Std. Z39.18

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Executive Summary

A parachute bag knife (P/N 71172) was received from the Aerial Delivery Engineering Support team of the U.S. Army Natick Research, Development and Engineering Center for analysis. The U.S. Army Research Laboratory subjected the part to hardness testing, chemical analysis, and metallography. Hardness readings taken directly on the component were affected by the presence of decarburization. Through microhardness testing, the decarburization was found to extend ~0.0055 in into the part from the surface. Microhardness testing also revealed the part had a core hardness of ~28 HRC. Chemical analysis showed the component conformed to the governing requirements for AISI 4130 alloy steel. Metallography revealed a pearlitic and ferritic microstructure, as well as possible evidence of the onset of martensite. This mixed structure may indicate a problem with attaining the correct austenitizing temperature, or problems with quenching. Metallography also showed that no decarburization existed along the edges of the blade, indicating that the manufacturer ground the blade after heat treatment. It is recommended that the AISI 4130 alloy component be quenched and tempered to produce a tempered martensitic structure leading to a harder and tougher knife edge. In addition, additions should be made to the engineering drawing to ensure quality parts in the future.

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1. Visual Examination

The as-received knife was photographed for documentation purposes (figures 1 and 2, representing the top and bottom of the part). As shown in the photographs, damage to the cutting edge was incurred. This anomaly is magnified in figure 3. The damage consisted of rolled metal, giving the appearance of a softer than nominal knife edge.

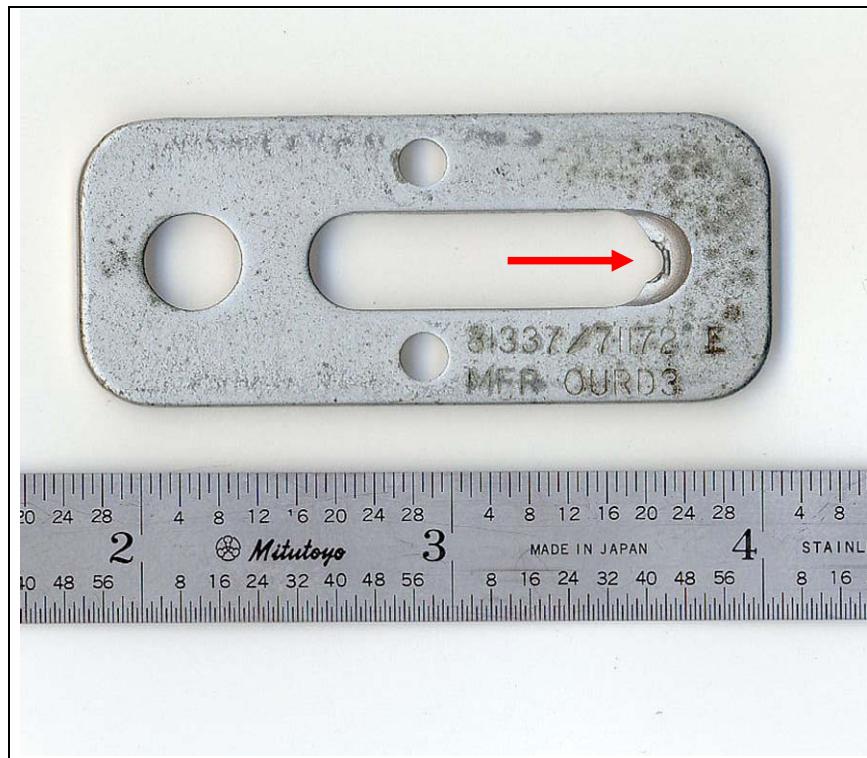


Figure 1. Top view of parachute bag knife, as-received. Note the damage to the knife edge (arrow) (magnified 1.75×).

2. Hardness Testing

The part was lightly sanded utilizing 180-grit silicon carbide paper to remove the zinc coating. Care was taken not to heat the part, so as not to affect the structure of the steel. Hardness measurements using the Rockwell "C" scale (150 kgf) were taken along the periphery of the component, as shown in figure 4. As the results in table 1 indicate, this part was rather soft for an ultrahigh-strength steel alloy (AISI 4130). There is no hardness requirement on the engineering drawing.



Figure 2. Bottom view of parachute bag knife, as-received (magnified 1.75×).



Figure 3. Damage to cutting surface, as-received (magnified 5×).

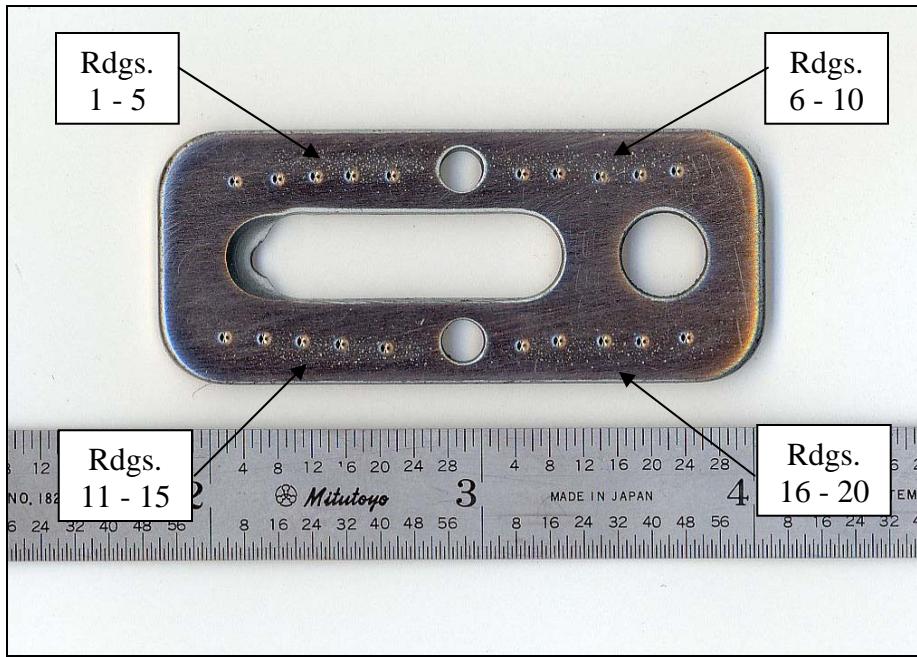


Figure 4. Hardness measurements taken directly on the component (magnified 1.4×).

Table 1. Results of hardness testing Rockwell “C” scale 150 kgf major load.

Reading	HRC	Reading	HRC
1	21.9	11	21.7
2	21.3	12	21.2
3	21.2	13	22.2
4	21.5	14	21.0
5	21.0	15	21.0
6	20.8	16	21.1
7	20.6	17	21.4
8	21.0	18	21.0
9	21.3	19	20.9
10	20.7	20	20.9
Average = 21.2 HRC			

3. Chemical Analysis

A section of the component (sectioning diagram shown in figure 5) was analyzed for chemical composition using wet chemistry techniques. The carbon and sulfur were detected utilizing the Leco combustion method, while the remaining elements were detected through direct current plasma spectroscopy. Governing specification SAE-AMS 6370¹ requires the chemical composition listed in table 2 for the AISI 4130 steel. As shown, the part met the requirements for AISI 4130.

¹ SAE-AMS 6370, Steel Bars, forgings, and Rings, 0.95 Cr – 0.20 Mo (0.28–0.33C) (SAE 4130), 17 May 2006.

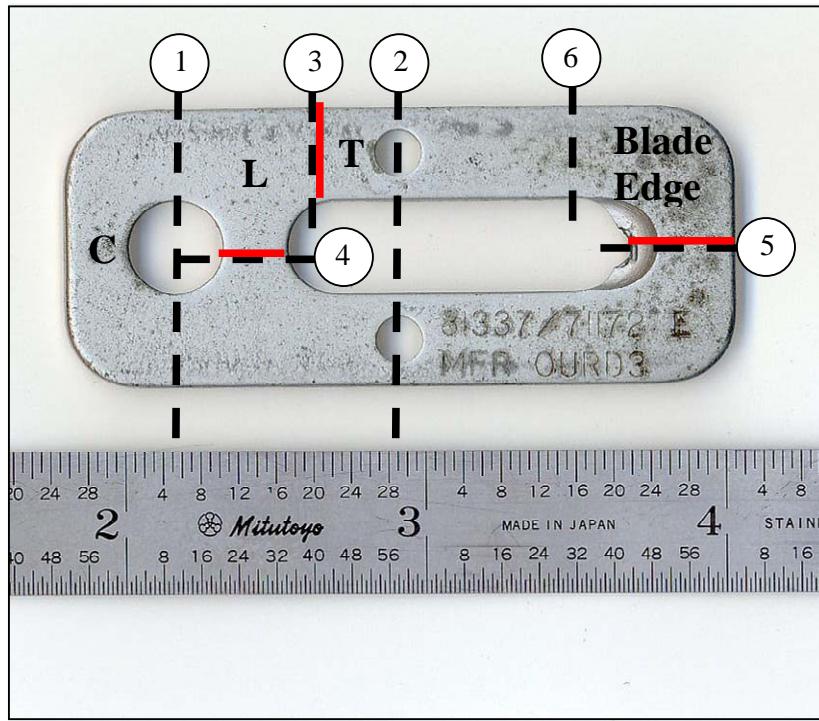


Figure 5. Sectioning diagram showing chemical analysis sample (C), longitudinal metallography sample (L), transverse metallography sample (T), and blade tip metallography sample. Dashed lines represent sectioned areas, red lines represent prepared planes (magnified 1.75 \times).

Table 2. Chemical analysis results, weight percent.

Element	SAE-AMS 6370 (AISI 4130)	Test Results
Carbon	0.28–0.33	0.31
Manganese	0.40–0.60	0.55
Silicon	0.15–0.35	0.22
Phosphorus	0.025 max.	0.0029
Sulfur	0.025 max.	0.005
Chromium	0.80–1.10	0.95
Molybdenum	0.15–0.25	0.20
Nickel	0.25 max.	0.0019
Copper	0.35 max.	0.015

4. Metallography

The pieces shown in figure 5 representing the longitudinal and transverse directions (as related to the length of the part) were metallographically prepared. The samples were ground on silicon carbide papers ranging in grit size from 240 to 2400. Rough polishing using 1- μm diamond

suspension was followed by final polishing using 0.05- μm alumina. The samples were analyzed in the as-polished condition and found to contain no gross defects or anomalies. The samples were subsequently etched in 2% nital to reveal the microstructure shown in figure 6. The structure showed evidence of lamellar pearlite and islands of ferrite, as well as possible evidence of martensite. This structure may indicate that the component was inadequately heat treated.²

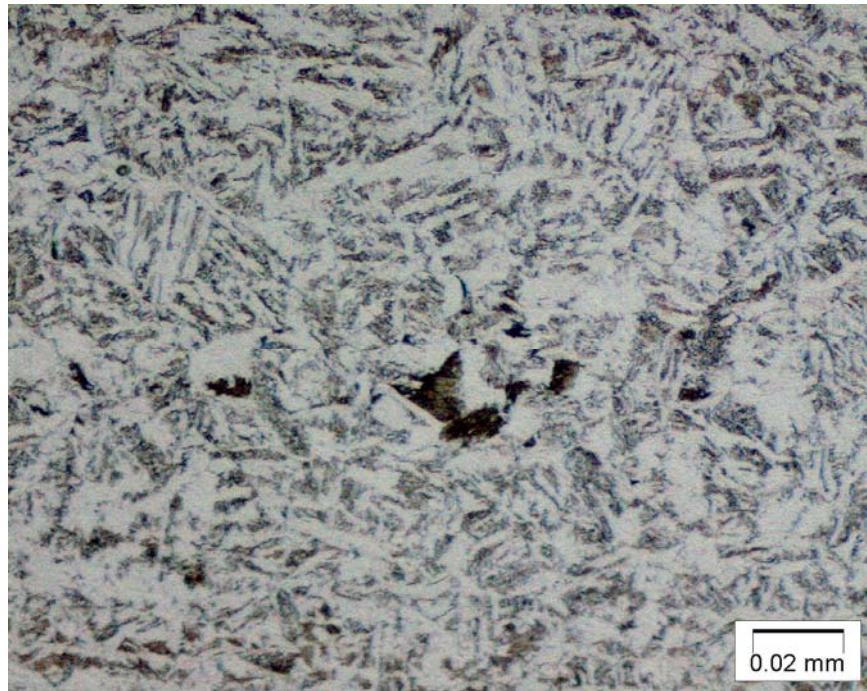


Figure 6. Microstructure of the component consisting of lamellar pearlite (dark areas) and ferrite (white areas), as well as possible martensite.
Etchant: 2% nital. (Magnified 500 \times .)

Governing specification SAE-AMS 6370 requires the following with respect to microstructure:

- Average grain size: Shall be ASTM No. 5 or finer determined in accordance with ASTM E112 (3.3.2).³
- Decarburization: Total depth of decarburization shall not exceed 0.010-inch for parts with a nominal distance between parallel sides less than 0.375 in (3.3.4.3).

The grain size was measured using the micrograph in figure 7 (100 \times) in conjunction with overlay slides conforming to ASTM E112. The average grain size was found to be approximately ASTM No. 9.5. Evidence of decarburization existed, as shown in figure 8. This condition (denoted by a predominance of ferrite at the surface) was prevalent around the periphery of the entire part.

² Correspondence with Jonathan Montgomery, Materials Engineer, U.S. Army Research Laboratory, 27 March 2006.

³ ASTM E112-96. Standard Test Methods for Determining Average Grain Size. *Annu. Book ASTM Stand.* **2004**.

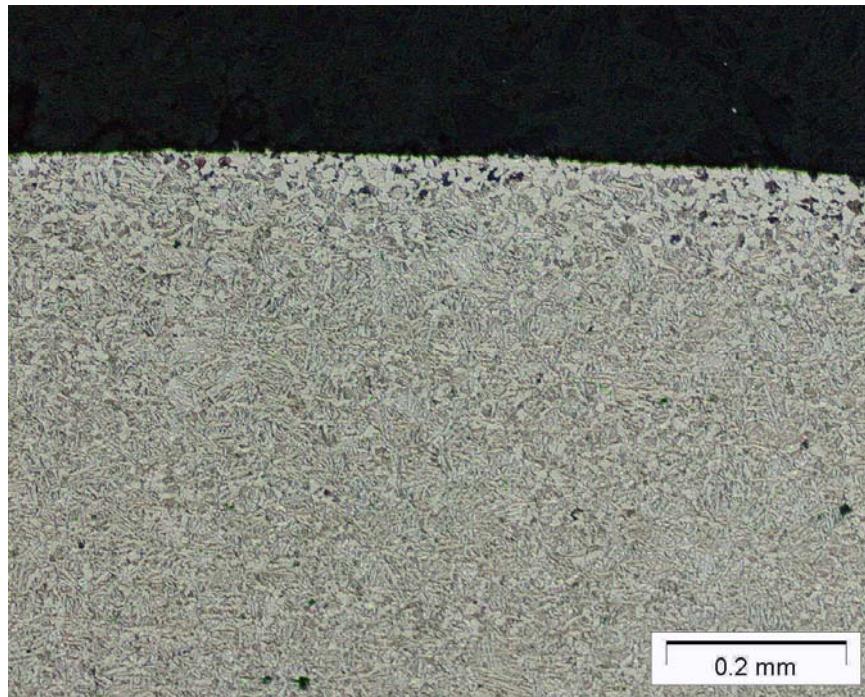


Figure 7. Micrograph used to measure grain size. ASTM E112 overlays were used to determine an average grain size of ASTM No. 9.5. Note evidence of banding. Etchant: 2% nital. (Magnified 100×.)

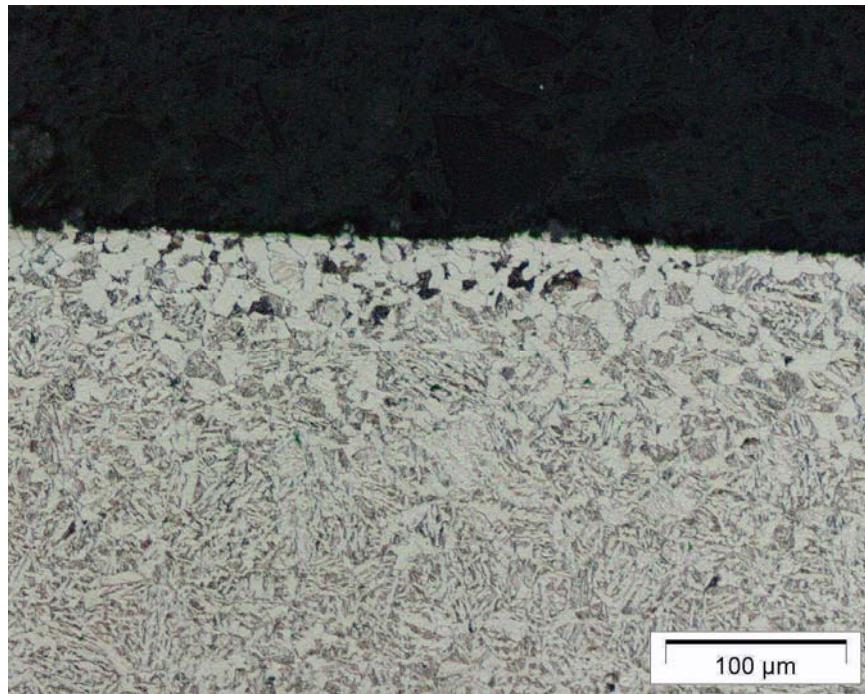


Figure 8. Evidence of decarburization at the surface of the component (white, blocky structure). Decarburization is characterized by ferrite structure at the surface. Etchant: 2% nital. (Magnified 100×.)

The sample consisting of a section made directly through the tip of the blade was also metallographically prepared as previously described. The intent was to determine if the manufacturer had ground the blade after heat treatment. Figure 9 shows the interface between the exterior surface of the knife and the blade tip. Note the layer of decarburization along the surface of the component, which ends where the blade begins. This was evidence that the manufacturer did indeed grind the blade after heat treatment. Figure 10 shows the deformed tip of the blade, while figure 11 (magnified view of figure 10) shows the grain flow within the tip.

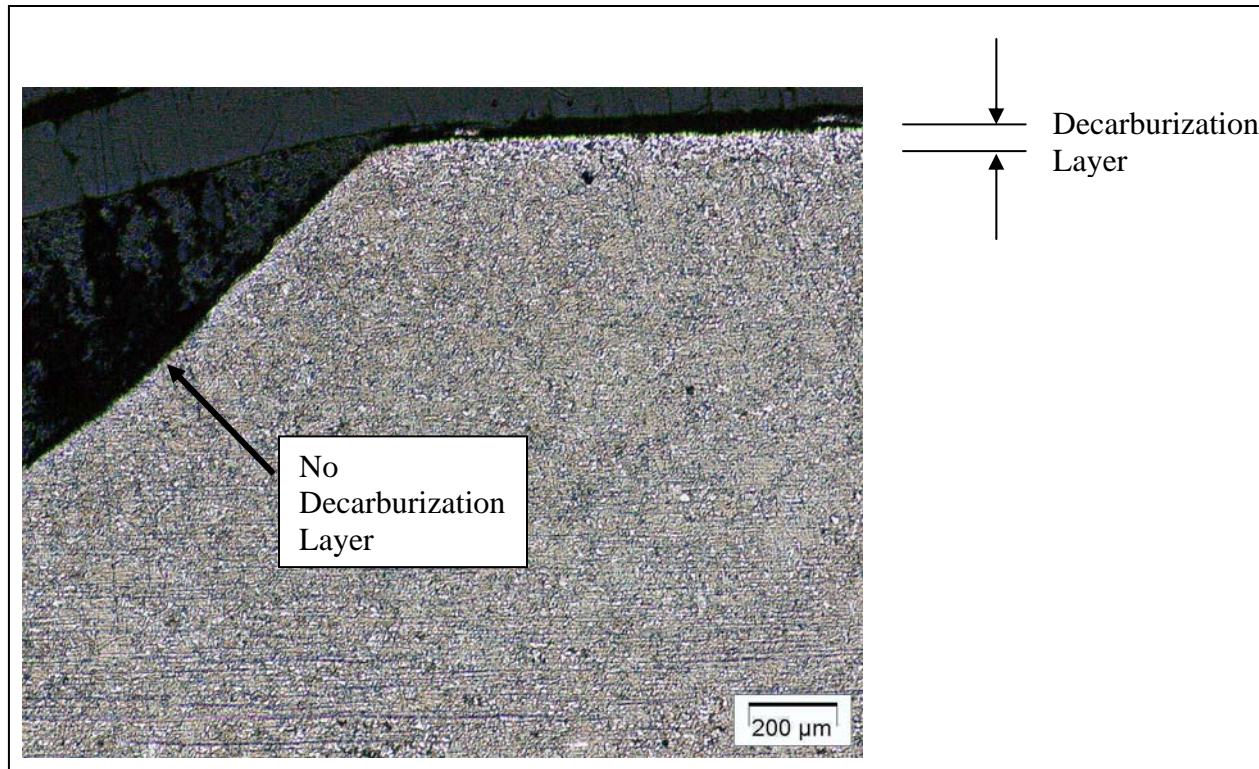


Figure 9. Decarburization at the surface of the component, but not on the blade edge. This shows manufacturer ground the blade after heat treatment. Etchant: 2% nital. (Magnified 50×.)

5. Microhardness Profile for Decarburization

A metallographically prepared sample was subjected to Knoop microhardness to determine the extent of the decarburization layer. As, the governing specification indicates, the total depth of decarburization shall not exceed 0.010 in for parts with a nominal distance between parallel sides less than 0.375 in (3.3.4.3). Table 3 contains the results of microhardness testing. As shown, the first four hardness readings were well below those of the remainder of the part (highlighted in red), indicating a depth of decarburization of ~0.0055 in. This was well within the 0.010-in requirement. Figure 12 shows a graphical representation of the Knoop microhardness readings, while figure 13 shows Knoop microhardness indents through the decarburization into the core.

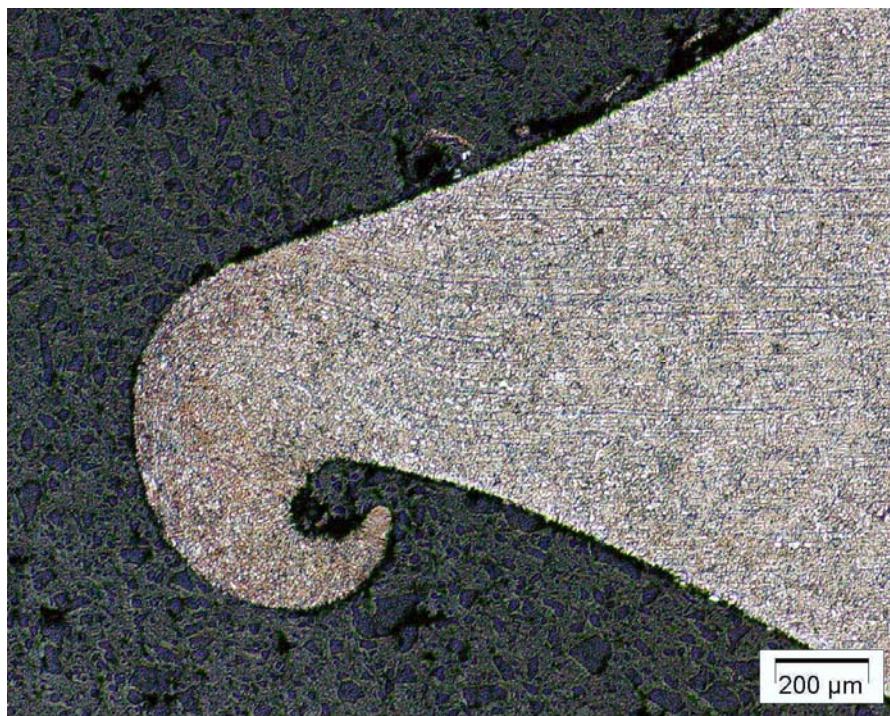


Figure 10. Deformed tip of the knife blade. Etchant: 2% nital. (Magnified 50×.)

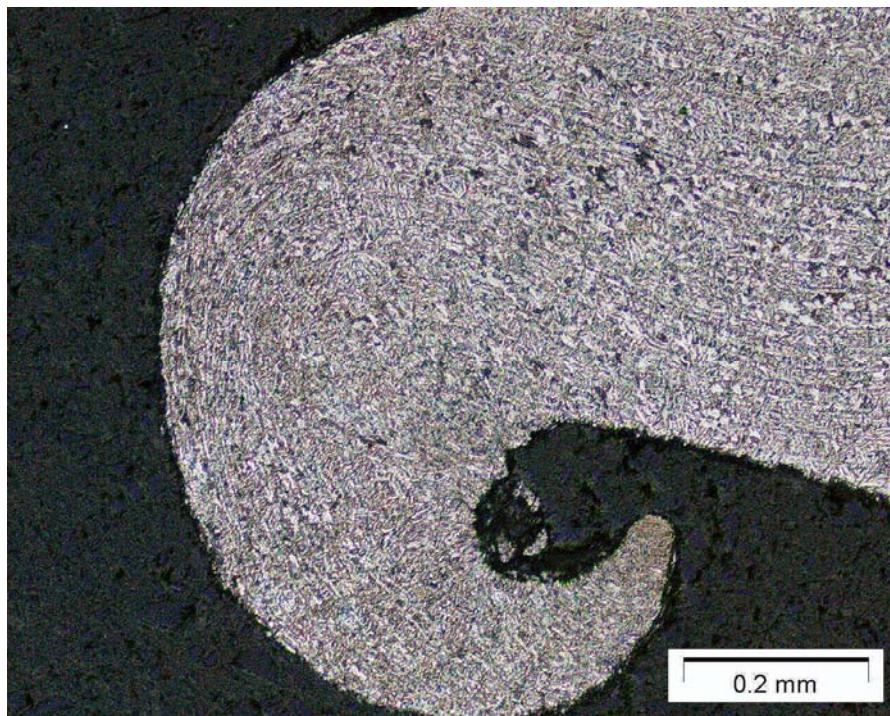


Figure 11. Magnified view of figure 10. Note the grain flow conforming to the contour of the swirl. Etchant: 2% nital. (Magnified 100×.)

Table 3. Results of microhardness testing Knoop scale 500 gmf major load, 20× objective.

Reading	HK	Approx. HRB/HRC	Depth From Surface
1	161.0	79.0 HRB	0.0015
2	197.6	89.3 HRB	0.0025
3	226.3	95.0 HRB	0.0035
4	264.1	22.6 HRC	0.0045
5	287.5	26.5 HRC	0.0055
6	289.3	26.8 HRC	0.0065
7	294.6	27.6 HRC	0.0075
8	286.0	26.3 HRC	0.0085
9	296.1	27.8 HRC	0.0095
10	300.3	28.4 HRC	0.0105
11	292.3	27.3 HRC	0.0115
12	300.3	28.4 HRC	0.0125
13	295.3	27.7 HRC	0.0135
14	304.7	29.1 HRC	0.0145
15	297.2	28.0 HRC	0.0155
16	298.8	28.2 HRC	0.0165

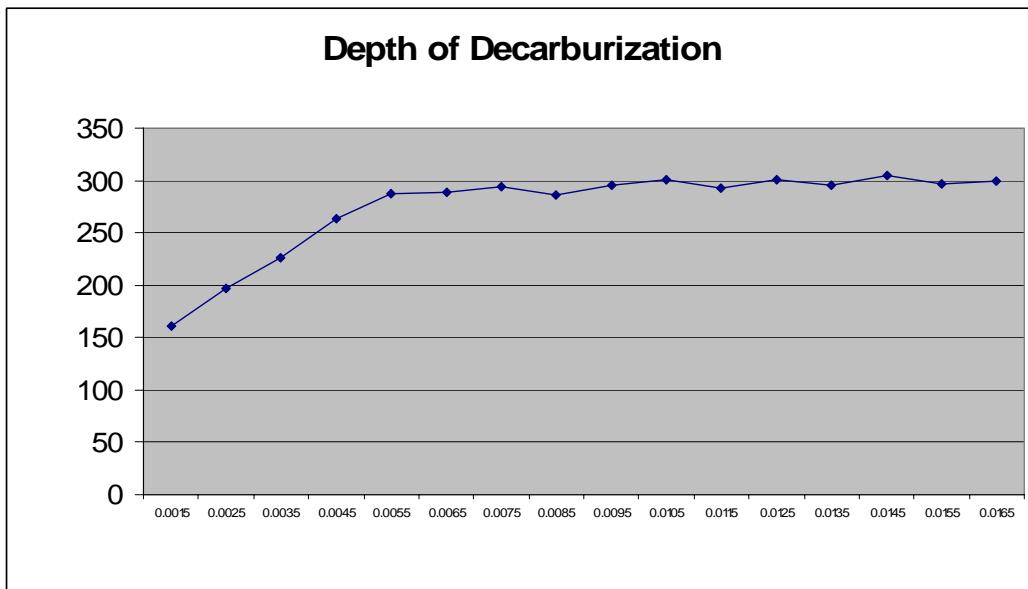


Figure 12. Plot of Knoop microhardness vs. depth below surface. Decarburization was determined to be ~0.0055 in deep.

It should be noted that the component core hardness level differs from the Rockwell “C” readings reported earlier in this report. This is most likely due to the fact that the decarburization layer deleteriously affected the Rockwell “C” readings. The readings listed in table 3 are a more accurate assessment of the component hardness. These readings compare favorably to the expected hardness of the microstructure noted.

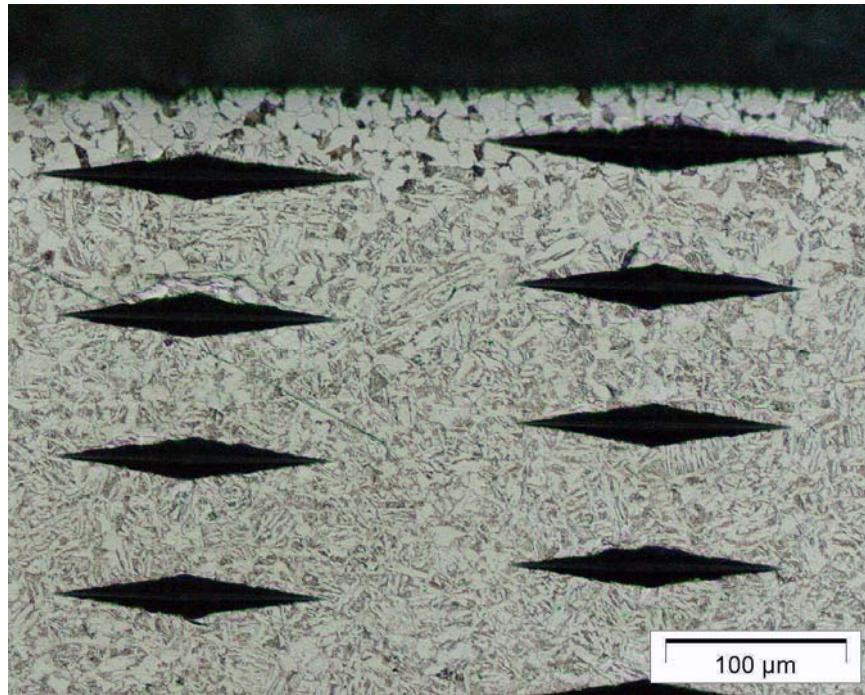


Figure 13. Knoop hardness indentations through the layer of decarburization at the surface of the component. Note the larger indents (indicating a softer material) within the decarburized region at the surface.
Etchant: 2% nital. (Magnified 200×.)

6. Conclusions

- Visual Examination: Damage to the cutting edge in the form of rolled metal was noted.
- Hardness Testing: The hardness readings taken directly on the part averaged 21.2 HRC.
- Chemical Analysis: The chemistry of the component compared favorably to the governing requirement for an AISI 4130 steel.
- Metallography: No gross defects were present in the as-polished condition. A 2% nital etchant revealed a microstructure of lamellar pearlite, islands of ferrite, and the possible onset of martensite. A layer of decarburization was noted around the periphery of the component. The HRC hardness readings taken directly on the part were most likely affected by the decarburization. No decarburization existed on the blade tip, indicating the manufacturer ground the blade after heat treatment.
- Microhardness: Knoop microhardness measurements were taken to determine the depth of decarburization. It was determined the decarburization was ~0.0055 in deep, well within the allowable 0.010 in. Microhardness testing showed an average component hardness of

28 HRC, which is a more accurate assessment of the overall hardness of the part. No hardness requirement is listed within the engineering drawing.

- The damage to the blade tip is evidence that the steel was softer than optimal for the intended purpose.
-

7. Recommendation

In general, knives are manufactured from quenched and tempered steel, resulting in a fine lath martensite microstructure. This is a much harder and tougher microstructure than pearlite and ferrite. It is recommended that future production of this component entail quenching and tempering of this alloy (per acceptable industry standards) to produce a part with a hardness in the upper 30's to lower 40's HRC. Heat treatment and hardness requirements should be added to Engineering Drawing 71172 to ensure quality components in the future. The U.S. Army Research Laboratory can provide assistance in this area if the U.S. Army Natick Research, Development and Engineering Center so chooses. In addition, it should be a requirement that the blade tip be ground after heat treatment. This would prevent decarburization from softening the tip.

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